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published in
Human Factors
2011

DOI (link to publisher)
10.1177/0018720811410976

document version
Publisher's PDF, also known as Version of record

>> Version of Record - Jul 19, 2011

OnlineFirst Version of Record - Jun 24, 2011

What is This?

The Validity and Interrater Reliability of Video-Based Posture Observation During Asymmetric Lifting Tasks

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Objective: The objective was to evaluate the validity and interrater reliability of a video-based posture observation method for the major body segment angles during asymmetric lifting tasks.

Background: Observational methods have been widely used as an awkward-posture assessment tool for ergonomics studies. Previous research proposed a video-based posture observation method with estimation of major segment angles during lifting tasks. However, it was limited to symmetric lifting tasks. The current study extended this method to asymmetric lifting tasks and investigated the validity and the interrater reliability.

Method: Various asymmetric lifting tasks were performed in a laboratory while a side-view video camera recorded the lift, and the body segment angles were measured directly by a motion tracking system. For this study, 10 raters estimated seven major segment angles using a customized program that played back the video recording, thus allowing users to enter segment angles. The validity of estimated segment angles was evaluated in relation to measured segment angles. Interrater reliability was assessed among the raters.

Results: For all the segment angles except trunk lateral bending, the estimated segment angles were strongly correlated with the measured segment angles ($r > .8$), and the intraclass correlation coefficient was greater than 0.75.

Conclusion: The proposed observational method was able to provide a robust estimation of major segment angles for asymmetric lifting tasks based on side-view video clips. The estimated segment angles were consistent among raters.

Application: This method can be used for assessing posture during asymmetric lifting tasks. It also supports developing a video-based rapid joint loading estimation method.

Keywords: posture observation, asymmetric lifting tasks, side-view video, body segment angles

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HUMAN FACTORS
Vol. 53, No. 4, August 2011, pp. 371–382
DOI:10.1177/0018720811410976

INTRODUCTION

Previous research indicated that awkward postures were strongly associated with work-related musculoskeletal disorders (Bernard, 1997; da Costa & Vieira, 2010). For example, a prolonged squatting posture was related to osteoarthritis (Coggon et al., 2000), trunk flexion and twisting were found to be linked with back disorders (Hoogendoorn, van Poppel, Bongers, Koes, & Bouter, 1999; Punnett, Fine, Keyserling, Herrin, & Chaffin, 1991; Tanii & Masuda, 1985), and overhead reaching was considered to increase the potential of shoulder injuries (Jonsson, Persson, & Kilbom, 1988). To reduce the injury caused by awkward postures, tasks that contain awkward postures need to be monitored.

Posture observation, either direct or video based, is one way to measure body posture. Many posture observation methods, such as Ovako Working Posture Analyzing System (OWAS; Karhu, Kansi, & Kuorinka, 1977), Rapid Upper Limb Assessment (RULA; McAtamney & Corlett, 1993), Posture, Activity, Tools, and Handling (PATH; Buchholz, Paquet, Punnett, Lee, & Moir, 1996), and Task Recording and Analysis on Computer (TRAC; van der Beek, van Gaalen, & Frings-Dresen, 1992), have been developed in the past few decades. All these methods help ergonomists identify the awkward postures in a job. Although posture observation is not as accurate as using laboratory equipment, such as cinematographic systems or electromagnetic field-based motion tracking systems, it still has been widely adopted by ergonomists to assess mechanical exposure (Juul-Kristensen, Fallentin, & Ekdahl, 1997). This wide adoption is because posture observation has a low cost, does not require specialized equipment, does not involve strong interference with the normal operations of those being surveyed, and can be done in the field (Bao, Howard, Spielholz, Silverstein, & Polissar, 2009; Hsiang, Brogmus, Martin, & Bezverkhny, 1998; Kilbom, 1994).

A good observational method should be both valid and reliable among different raters (Bao et al., 2009; Corlett, Madeley, & Manenica, 1979). *Validity* refers to whether the estimated body segment angle is close to the true value, and *interrater reliability* refers to whether different raters yield consistent estimates for a body posture. Previous research has shown that posture observation of different body segment angles has various levels of validity. Although the validity of torso flexion is low (deLooze, Toussaint, Ensink, Mangnus, & van der Beek, 1994), the validities of shoulder elevation, shoulder plane of elevation, and elbow flexion are relatively good (Lowe, 2004a). It also has been found that the validity for static tasks is better than that for dynamic tasks in on-site observation. This difference may be attributable to the capability limitation of observing simultaneous information, which can be improved by using video recordings (Leskinen et al., 1997; Spielholz, Silverstein, Morgan, Checkoway, & Kaufman, 2001).

Interrater reliability of posture observation also varies among different body segments. Whereas the shoulder joint angle tended to associate with a low interrater reliability (Burt & Punnett, 1999), the elbow joint yielded a relatively good interrater reliability (Bao et al., 2009). It was also found that the experience of the raters and the playback speed of the video could alter the classification criteria of the raters during the observing (Keyserling, 1986; Kociolek & Keir, 2010).

Lifting is a very common movement for many occupations. Excessive loading of the L5/S1 joint during lifting tasks is an occupational low-back-pain risk factor (Granata & Marras, 1999; Marras, 2000). Some posture observation methods have been adopted for identifying awkward trunk postures during material handling tasks (deLooze et al., 1994; Neumann, Wells, Norman, Kerr, et al., 2001). The static (Neumann, Wells, Norman, Frank, et al., 2001) and cumulative L5/S1 joint loading (Sutherland, Albert, Wrigley, & Callaghan, 2008) can be estimated directly from the observed postures combined with a biomechanical model.

A postural observational method can be used not only to identify awkward postures during lifting tasks but also to estimate the dynamic L5/S1 joint loading during lifting tasks. A video matching method of symmetric lifting tasks (Chang, Hsiang, Dempsey, & McGorry, 2003; Hsiang et al., 1998) was proposed in which the lifter's joint angular trajectory was interpolated on the basis of observer-identified continuous major joint angles of four key lifting postures extracted from side-view lifting video clips. The dynamic L5/S1 joint loading was estimated from these interpolation-based body segment movements combined with a biomechanical model. However, there are a few limitations to this previous video matching method. Since asymmetric lifting tasks are quite common, the validity of posture matching during asymmetric lifting needed to be assessed. In addition, how postural matching performance varies across different raters is unknown.

To further develop a video matching method, a continuous posture-observation method to estimate the main segment angles during asymmetric tasks was proposed in this study. The main objective was to evaluate the validity and the interrater reliability of this observation method. A lifting task was designed to provide motion tracking system-based direct recording and the video clips with which the postures would be estimated by the raters with a custom-developed program. Validity was evaluated in relation to the motion tracking system. Interrater reliability was assessed among the observers who were experienced in ergonomics or kinesiology.

METHOD

For this study, 12 healthy male lifters (age, $M = 47.5$ years, $SD = 11.3$; height, $M = 1.74$ m, $SD = 0.07$; weight, $M = 84.5$ kg, $SD = 12.7$) performing various lifting tasks in a laboratory were recorded by both a side-view camcorder and a synchronized motion tracking system that directly measured the body movement. In addition, 10 raters (age, $M = 37.0$ years, $SD = 16.7$) observed the movement of the lifters and estimated their body segment angles by watching the video clips with customized software. The experimental protocols for the study were approved by the appropriate institutional review boards for the

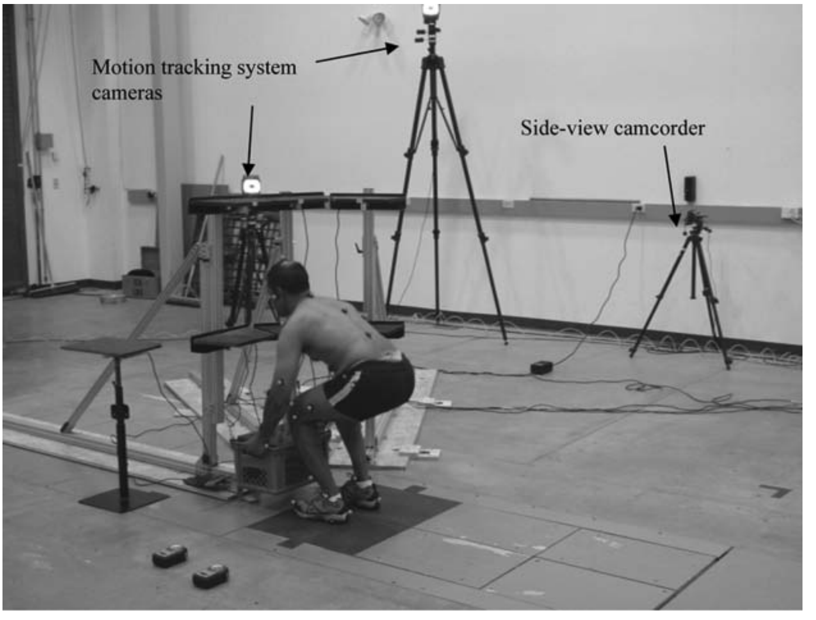

Figure 1. Experimental setup for the lifting tasks. The regular camcorder was on the rightmost tripod and recorded the lifting tasks from the side view. Markers on the participants were used for monitoring body movement. A total of 10 cameras were used for the motion tracking system; only 2 of them are shown in this picture.

protection of human participants, and all lifters and raters gave informed written consent.

The Simulated Lifting Task

The simulated laboratory task involved lifting a plastic crate (39 × 31 × 22 cm) weighing 10 kg with three vertical lifting ranges and three end-of-lift asymmetric angles (Figure 1). The three lifting ranges were floor to knuckle height, floor to shoulder height, and knuckle height to shoulder height. The three end-of-lift asymmetric angles were 0°, 30° to the right, and 60° to the right, with the initiation of lift occurring with no asymmetry. Lifters were instructed to not move their feet after the lift was initiated. No instructions about the initial horizontal distance from feet to crate or the lifting speed were provided; those dimensions were chosen by the lifters. For each lifting condition, two repetitions were performed, providing a total of 18 lifts (3 × 3 × 2) total. The order of the vertical ranges and asymmetric angles was randomized for each lifter.

A previous study showed that better accuracy could be reached when the filming angle was orthogonal to the participant's sagittal plane during symmetric lifting (Chang, McGorry, Lin, Xu, & Hsiang, 2010). Considering that the whole body of a lifter was in the sagittal plane during the liftoff and the lower extremities of a lifter were mainly in the sagittal plane during the set-down for the simulated lifting tasks, a digital camcorder (GR-850U, JVC, Japan) was placed on the side 4 m away from the lifters and was mounted 1 m above the ground. Since the lifters were instructed to rotate to the right, the camcorder was placed on the same side of the trunk rotation to eliminate blocking the view of the upper extremities by the trunk. Thus, the camcorder recorded the lifting task from the side view (90° to the right of the initial lift position) for each trial of each lifter, generating 216 video clips (12 lifters × 18 lifts). Because two video clips were missed during the experiment, 214 video clips were used for the observation.

Observational Methods

All the raters participating in this study were recruited from the New England area of the

TABLE 1: List of Segment Angles to Be Estimated

Body Segment	Segment Angle Definition
Shank	The angle between the projection of shank on global *Z-X* plane and the horizontal plane
Thigh	The angle between the projection of thigh on global *Z-X* plane and the horizontal plane
Upper arm	The angle between the projection of upper arm on the sagittal plane of trunk and the horizontal plane
Forearm	The angle between the projection of forearm on the sagittal plane of trunk and the horizontal plane
Trunk, sagittal	The angle between the projection of trunk on global *Z-X* plane and the horizontal plane
Trunk, rotational	The angle between the projection of trunk on global *X-Y* plane and the global *Y-Z* plane
Trunk, lateral bending	The angle between the projection of trunk on global *Y-Z* plane and the global *Z-X* plane

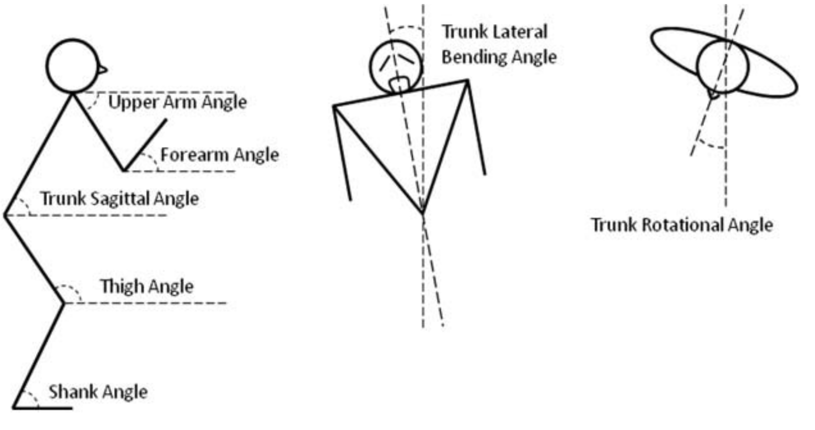

Figure 2. The segment angles to be estimated. In the posture shown in this figure, the segment angle of the upper arm is negative, and all other segment angles are positive.

United States through posters in universities, communities, and Craigslist.com and had knowledge and experience in ergonomics and/or kinesiology. The average years of experience was 9.4 years and ranged from 1 to 36 years. In terms of their highest degree, 3 held a doctoral degree, 3 held a masters degree, and 4 held a bachelors degree.

Body segment angles to be estimated in this study were similar to those described by Chang et al. (2003), which included shank, thigh, upper arm, forearm, and trunk sagittal angles (Table 1 and Figure 2). In addition, since the current study extended the posture observations to asymmetric lifting tasks, trunk rotational angle and trunk lateral bending angle were also estimated. For the posture of the extremities, although they were approximately symmetric to the trunk sagittal plane for the simulated lifting tasks, the raters were asked to estimate the average segment angle between the left side and right side if they believed the postures in the two sides were different.

The raters performed body posture estimations with a custom-developed computer program that involved uploading the video clip for a given lift, selecting four appropriate frames from the clip, entering the observed angles into the program, reviewing an animation of the entered angles, and refining the estimation on the basis of the

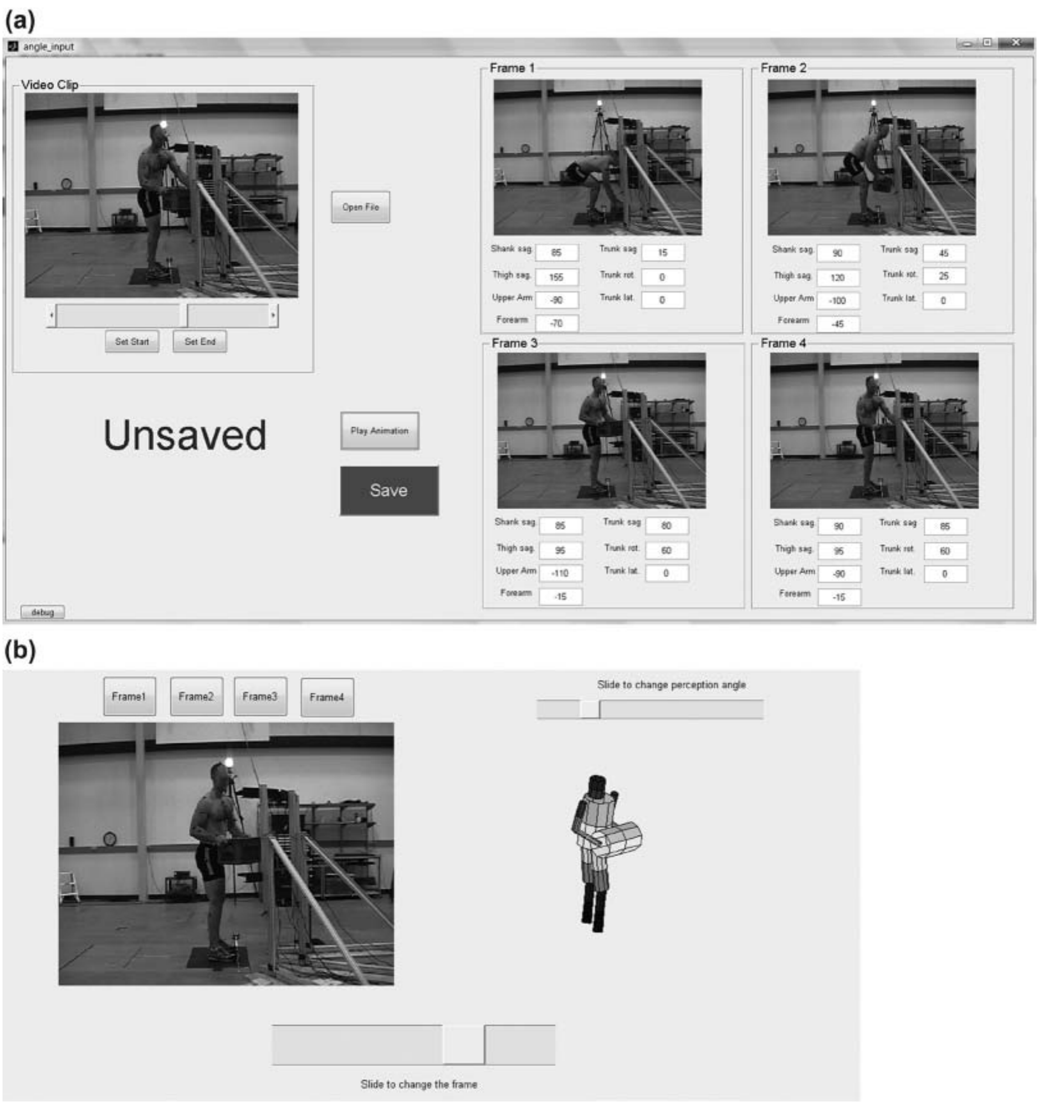

Figure 3. (a) A screenshot of the user interface of the program the raters used for esimating major segment angles during asymmetric lifting tasks. The interface contains the complete video clip playback (left), the controls to select the start and end frames for the lift, and the four frames in which to enter the segment angles. (b) A screen-shot of the computer program mannequin animation showing the playback controls. Clicking “Frame1” to “Frame4” buttons would lead to the still posture comparison, and sliding the slide bar at the bottom would lead to the movement comparison. The movement was generated by applying cubic spline interpolation on major segment angles of the four rater-estimated key frames. By comparing the posture in the key frames and the movements of the mannequin to the lifter in the video clip, the rater can refine the angle estimations.

animation (Figure 3a). Selecting the frames required the user to identify the frame where the crate was just lifted from the ground and the frame where the crate initially touched the destination shelf.

Since the use of four frames is suggested to describe a lifting task (Hsiang et al., 1998), the program then automatically selected two other frames between the two frames selected by the rater with equal time-space. For example, if the two frames selected by a rater were at time T and $T + \Delta t$ of a video clip, the two frames selected by the program were at time $T + \Delta t/3$ and $T + 2\Delta t/3$. For each of the four frames, the raters were required to estimate all seven segment angles and input them into the program interface.

After the raters estimate the segment angles for the four key frames, they can play back an animation of a mannequin emulating the lifting task. The animation is automatically generated by the custom-developed software on the basis of the entered postures from the four frames and with the application of cubic spline interpolation on the major segment angles of the four rater-estimated key frames (Xu, Chang, Faber, Kingma, & Dennerlein, 2010b; Figure 3b). The body segment dimensions of the mannequin are based on the anthropometry data reported in Roebuck, Kroemer, and Thomson, (1975). With the anthropometry data, the trunk is drawn as one single segment. The azimuth of the view angle of the mannequin is by default the side view, which matches the view angle of the camcorder but can be modified by the raters if they wish. By comparing the posture in the key frames and the movement of the mannequin and the lifter in the video clip, the rater can refine the original estimation of the segment angles.

The raters were instructed that when they were satisfied that the animation matched well the video clip, they could save their final postures and move on to the next video clip. In total, each rater needed to code 846 frames (4 frames × 214 video clips). The sequence of video clips was randomized for each rater. Before the observation, training was provided to the raters with 3 sample video clips of lifting tasks. A goniometer and a set of photos showing different levels of trunk lateral bending and trunk rotation were provided to the raters for assisting them in making a better posture estimation; however, the raters could decide for themselves whether to use them during the experiment.

Direct Measurement

Whole-body kinematics of the lifters was measured with the use of a passive motion tracking system based on a method similar to that described by Kingma, deLooze, Toussaint, Klijnsma, and Bruijnen (1996). The reflective markers were taped on anatomical landmarks of body (Cappozzo, Catani, Della Croce, & Leardini, 1995). The 3-D space positions of markers were measured by a motion tracking system (MotionAnalysis, Santa Rosa, CA) with a sampling rate of 100 Hz. The raw 3-D coordinate data were filtered with a fourth-order Butterworth zero-lag low pass filter at 8 Hz. From these data, the instantaneous orientations of the anatomical axes for the measured body segments were calculated across the entire lift (Kingma et al., 1996). The Euler angles of each body segment were calculated on the basis of the instantaneous orientation of the anatomical axes system of each body segment with respect to the global coordinate system. The sequence of Euler angles decomposition was Y-X-Z (sagittal plane flexion–coronal plane lateral bending–transverse plane rotation).

Data Analysis

Validity. For each body segment angle estimated by the raters from the video clips, the corresponding measured body segment angle was extracted from the synchronized motion tracking system. The measured segment angle subtracted from the estimated segment angle was defined as the estimation error. For each body segment, we compared the estimated segment angles with the measured ones by calculating the correlation coefficient and the average of the absolute estimation error among all four frames of all the video clips. The box plots were used to show the distribution of the estimation error for each body segment angle. A linear regression was also performed between the estimated body segment angles and the measured ones. For each rater, the elapsed time used for coding each video clip (four frames) was recorded. The effect of cumulative observing time on the estimation errors was analyzed.

Interrater reliability. To quantify interrater reliability, intraclass correlation coefficient (ICC) was calculated across all four frames for each body segment angle. Since the raters in this study were randomly selected from a population of raters, ICC (2, 1) was adopted, as suggested by Shrout and Fleiss (1979). As recommend by Portney and Watkins (1993), the reliability was considered good when ICC was greater than 0.75

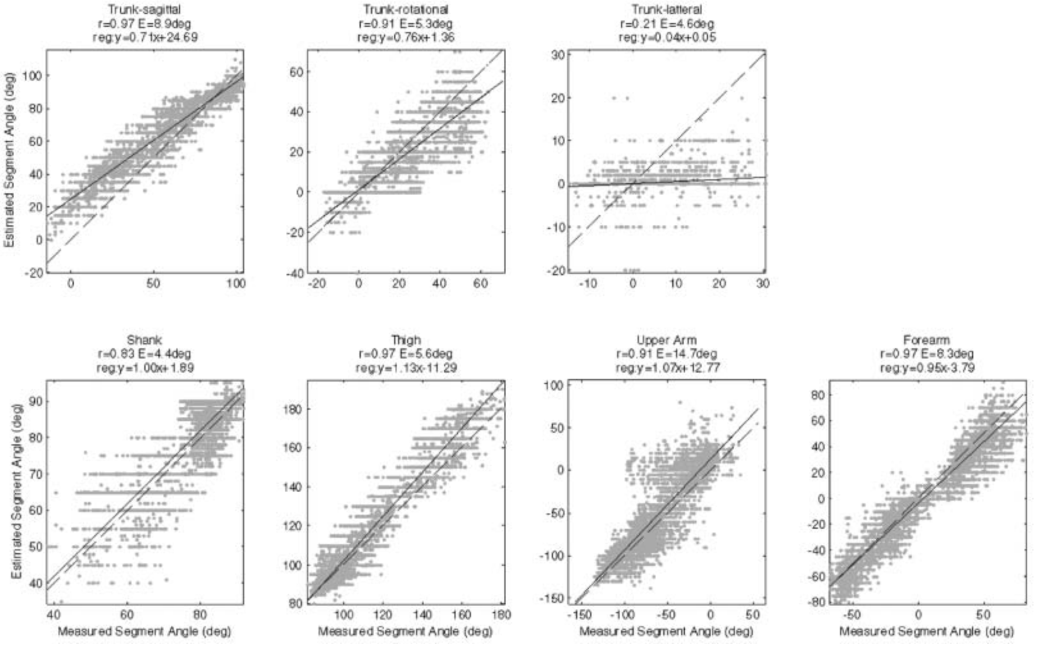

Figure 4. The estimated segment angles versus the measured segment angles for all the video clips and all the raters. r = correlation coefficient; E = average of the absolute estimation error. The solid line is the linear regression line. The dashed line is the diagonal.

and poor to moderate when ICC was less than 0.75. We calculated the standard deviation of estimated body segment angles among all raters and all four frames by pooling the standard deviation across the video clips to quantify between-rater variability (Bao et al., 2009).

RESULTS

Validity

Within the ranges of body segment angles in the simulated lifting tasks, the estimated segment angles were strongly correlated with the measured segment angles for all the segment angles ($r > .8$) except the trunk lateral bending angle, for which the correlation coefficient was only 0.21 (Figure 4). The average of the absolute estimation error was within 10° for all the segment angles except the upper arm, for which the error was 14.7° (Figure 4). Based on the box plots of the estimation errors (Figure 5), raters overestimated the segment angles for the trunk sagittal angle, trunk rotational angle, shank angle, thigh angle, and upper arm angle and underestimated the segment angles for the trunk lateral bending angle and forearm angle. Figure 4 shows that when the trunk bent forward (the trunk sagittal angle moved from 90° to 0°), the raters tended to overestimate the trunk sagittal bending more. The average coding time among all the raters for each video clip (four frames) was 4.4 min ($SD = 0.9$). A statistical test revealed that the cumulative observing time did not have significant effect on the estimation errors of any of the segment angles ($p > .05$). This indicated that exposure to the observing process did not change the accuracy level of the raters.

Interrater Reliability

The ICC was greater than 0.75 for most of the body segment angles except for trunk lateral bending. For the thigh, upper arm, forearm, and trunk sagittal angle, the corresponding ICCs were greater than 0.9 (Table 2). The pooled standard deviations of all the body segment angles were less than 15°. The upper arm had the largest value, 13.4°, and trunk lateral bending had the smallest value, 1.3°.

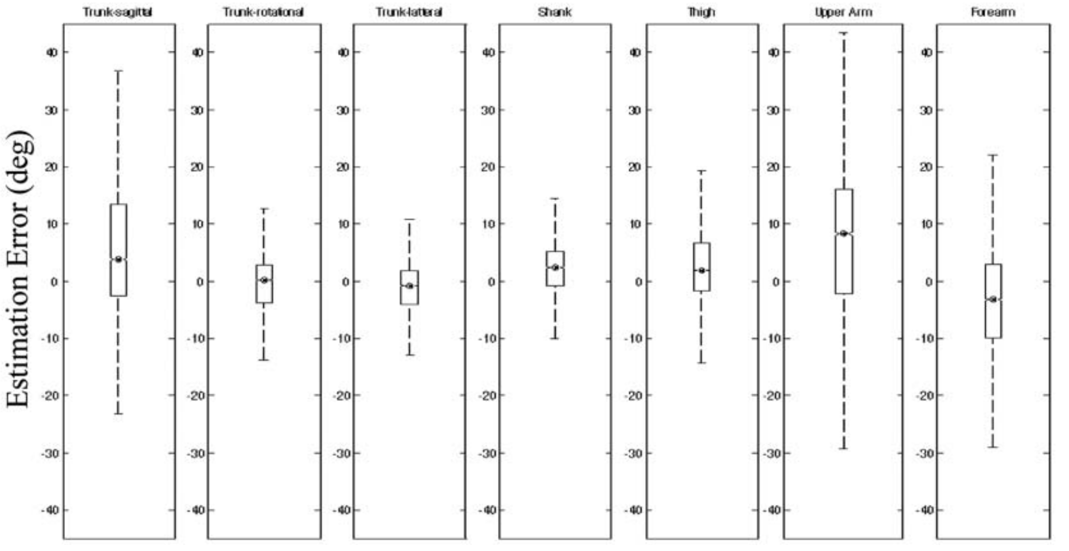

Figure 5. Bar plot showing the distribution of the estimation error of the major segments. The middle notch is the mean, the box represents 25th percentile and 75th percentile, and error bars represent the maximum and the minimum value.

TABLE 2: The Intraclass Correlation (ICC) Coefficients and Pooled Standard Deviations of All Segments Estimated

Body Segment Angle	ICC	Pooled Standard Deviation (in degrees)
Shank	.77	4.4
Thigh	.95	5.8
Upper arm	.90	13.4
Forearm	.95	9.1
Sagittal trunk	.94	5.4
Rotational trunk	.85	5.9
Lateral trunk	.05	1.3

DISCUSSION

The goal of this research was to investigate the validity and interrater reliability of a posture observational method of asymmetric lifting tasks. For the seven investigated segment angles, the correlation coefficients and the average estimation errors (Figure 4) indicated that this posture observational method can provide a robust estimate of the segment angles except for the trunk lateral bending, which was not fully evaluated because of the limited range of motion tested. The ICC and the pooled standard deviation showed a general agreement between the raters on the estimated segment angles. The range of the pooled standard deviation was consistent with previous research (Bao et al., 2009).

Upper arm had the largest absolute estimation error among all segment angles, which was 14.7°. This error was larger than the result of a previous study (Genaidy, Simmons, Guo, & Hidalgo, 1993), in which the absolute error of observed shoulder flexion in the sagittal plane was less than 10°. Figure 4 shows that there were a few trials in which the rater-estimated segment was approximately 0° (upper arm was horizontal to the ground) and the measured angle was approximately −90° (upper arm was vertical to the ground and at the side of the trunk).

Such discrepancy may be attributable to the arm abduction. During the lifting experiment, a few lifters tended to have approximate 90° arm abduction when the box reached the highest point of the lifting course. For example, when the arm abduction angle is 85°, the raters may estimate the upper arm angle as 0° when they observe such posture from the side view. However, the Euler angles (*Y-X-Z* sequence) of the upper arm measured by the motion tracking system in our study were

(−90°)-(+85°)-(0°), which yielded the upper arm angle as −90°. It is unclear whether asking the raters to estimate the 3-D rotation of the upper arm can solve this problem because previous research (Lowe, 2004b) found that observers had low precision and reliability on 3-D shoulder joint angle estimations.

The trunk lateral bending angle had the smallest correlation coefficient ($r = .21$) between the rater-estimated angle and measured angle, although the average absolute error was only 4.57°. Most rater-estimated trunk lateral bending angles were between −10° and 10° regardless of the measured angles. Further analysis showed that 93.5% of the estimated trunk lateral bending was rated as 0°, even though the measured angle ranged from −20° to 30°. One possible reason for this discrepancy was that the observer watched the lifting tasks from the side view, where a small amount of lateral bending was hard to observe. Ideally, for estimating lateral bending, the rater should observe the lifting tasks from the front or rear view, since the perception error would be minimized when the observing angle was orthogonal to the body movement plane (Chang et al., 2010). However, such viewing angles could inflate the estimation error for the body movement in the sagittal plane, which contributed the majority of the body movements during the lifting tasks.

Another reason was that the capability of observers to distinguish differences of segment angle was limited. The authors of a previous study reported that the optimal category size for trunk lateral bending was 15°, and shortening the category range resulted in a greater number of misclassifications (van Wyk, Weir, Andrews, Fiedler, & Callaghan, 2009). In the current study, 85% of the lateral bending angles in the frames that needed to be estimated were between −5° and 15°, which did not provide a large enough variance that the raters could distinguish.

The small variance of trunk lateral bending could also explain why trunk lateral bending had the smallest ICC and also the smallest pooled standard deviation. Generally, the ICC is large when the interrater variance is small because the ICC indicates how much of the total variance of rating is not attributable to interrater variance. However, as pointed out in a previous study (Bao et al., 2009), when the posture variance is small, the ICC could be poor even when the interrater variance is small. In the present study, because most raters estimated trunk lateral bending as zero, the corresponding ICC was only 0.05 even though the standard deviation was 1.3°.

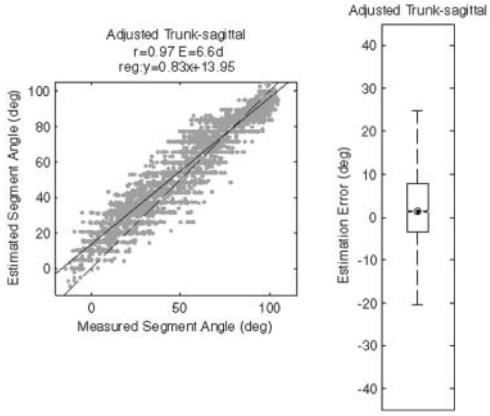

Figure 6. Left: The estimated trunk sagittal angle versus the measured one after the estimated trunk sagittal angle was adjusted by the orientation of the lumbosacral joint. Right: The distribution of the estimation error for the adjusted trunk sagittal angle.

The trunk sagittal angle tended to be overestimated (for bending posture) when the trunk was bent more forward because of the different definitions of trunk between the raters and the motion tracking system (Figure 4). Whereas raters used the hip-acromion link to estimate the trunk sagittal angle, the motion tracking system used the L5/S1-acromion link to do so, which made the trunk seem to bend more forward, thus reducing the trunk sagittal angle. Although it is hard to justify which definition is the correct one for representing the trunk, the use of different definitions had introduced a systemic error into the study. To eliminate this error, the lumbosacral orientation model (Anderson, Chaffin, & Herrin, 1986) can be adopted whereby the orientation of the L5/S1-acromion link can be calculated by the orientation of the hip-acromion (i.e., rater-estimated trunk sagittal angle) and the rater-estimated knee angle. After the rater-estimated trunk sagittal angle was adjusted by this model, the average absolute error decreased from 8.9° to 6.6° ($p < .05$). The intercept of the linear regression decreased from 24.69° to 13.95°. Since the intercept was the estimation error when the trunk sagittal angle was 0°, a decrease in the intercept indicated that the level of overestimation during the sagittal trunk bending was reduced (Figure 6).

Although the coding time of each video clip (four frames) was within a tolerable time length, it was also found that the coding time was shorter as the raters coded more video clips. For the first 20 video clips, the average coding time of each video was 6.1 (*SD* = 0.6) min. For the last 20 video clips, the average coding time of each video was 2.8 (*SD* = 0.5) min. Such results indicated that a learning effect existed. A further analysis of learning curve was then performed (Nahmias, 2001), and the results showed that the learning curve in this study was an 88% learning curve, which indicated that the time required for coding the 2*n*th video clip was 88% of the time required for coding the *n*th video clip. This time difference showed that for the experienced raters, their coding could be more effective after they were familiar with the coding process.

Future studies should apply this observational method on L5/S1 joint moment estimation during asymmetric lifting tasks. Recent studies (Xu et al., 2010b) have shown that 4-point cubic spline interpolation of body segment angles can provide a robust estimation of segment angular trajectories. With further development, it may be possible to perform the interpolation on the observed body segment angles to approximately regenerate full body movement during asymmetric lifting tasks without using complicated motion tracking systems. The L5/S1 joint loading could be then calculated from the body movement combined with a biomechanical model (Xu, Chang, Faber, Kingma, & Dennerlein, 2010a). However, the error of L5/S1 joint loading attributable to perception error of the posture observation needs to be investigated further.

There were some limitations of this study that need to be addressed. First, only limited lifting conditions controlled within a confined range were performed in the simulated lifting tasks. For instance, all asymmetric lifting tasks started from a symmetric lifting position and were to the right side, the lifting heights were relative to the stature of the lifters rather than fixed, and the feet position of the lifters was fixed on the ground during the lifting tasks. Such experimental designs provided a good scenario for testing validity and interrater reliability; however, they may also restrict generalizing the results to other lifting tasks that might introduce more errors attributable to perception difficulty.

Second, only side-view video clips were provided to the raters. In real-world field surveys, recording from the side view might be not applicable because of the working conditions of a job. In that case, the current results could be altered, as the view angle has a significant effect on perception errors (Chang et al., 2010). In addition, since there has been evidence that multicamera view angles could help raters improve the joint angle estimation during running (Krosshaug et al., 2007), additional studies should investigate whether synchronized video clips of different view angles would reduce the observational error for asymmetric lifting tasks. Third, only raters with a background in ergonomics and/or kinesiology were recruited for the experiment. It is expected that people doing rating in the field may not have those backgrounds or experiences of posture observing. Future research with raters of different backgrounds is needed to generalize these results.

Fourth, the lateral bending angle in the simulated lifting tasks was within a small range. Thus, the validity of the lateral bending in this study cannot be generalized for a large range of motion of lateral bending. Fifth, a motion tracking system was used in the current study and provided the gold standard of segment angles. Those measured segment angles, however, might be not perfectly accurate because of measurement errors and could introduce slight noise into the perception errors shown in this study. Sixth, motion tracking system markers were placed on the lifters' bodies, which may have helped the observers identify the center of the joints. If this observational method is adopted for a field survey, the clothes or personal protective equipment lifters are wearing could block the rater's view and reduce the perception of the centers of the joints.

CONCLUSION

The proposed observational method was able to provide a robust estimation of major segment angles for simulated asymmetric lifting tasks with the use of side-view video clips. The estimated angles for each body segment were consistent among different raters. The coding time of each video clip was within a tolerable time length. Future studies may focus on applying this observational method for joint loading estimation during asymmetric lifting tasks.

ACKNOWLEDGMENT

The authors are grateful to Angela DiDomenico and Yulan Liang for many useful comments and suggestions and to Jacob Banks and Niall O'Brien for assistance in data collection.

KEY POINTS

- The proposed observational method was able to provide a robust estimation on major segment angles for asymmetric lifting tasks with the use of side-view video clips.
- The estimated segment angles were consistent among raters.
- With further development, not only could this method be used for posture assessment tools but it could also provide support for developing a video-based joint loading estimation method in the future.

REFERENCES

Anderson, C. K., Chaffin, D. B., & Herrin, G. D. (1986). A study of lumbosacral orientation under varied static loads. *Spine*, *11*, 456–462.

Bao, S., Howard, N., Spielholz, P., Silverstein, B., & Polissar, N. (2009). Interrater reliability of posture observations. *Human Factors*, *51*, 292–309.

Bernard, B. P. (Ed.). (1997). *Musculoskeletal disorders and workplace factors: A critical review of epidemiologic evidence for work-related musculoskeletal disorders of the neck, upper extremity, and low back* (DHHS Publication No. 97-141). Cincinnati, OH: National Institute for Occupational Safety and Health.

Buchholz, B., Paquet, V., Punnett, L., Lee, D., & Moir, S. (1996). PATH: A work sampling-based approach to ergonomic job analysis for construction and other non-repetitive work. *Applied Ergonomics*, *27*, 177–187.

Burt, S., & Punnett, L., 1999. Evaluation of interrater reliability for posture observations in a field study. *Applied Ergonomics*, *30*, 121–135.

Cappozzo, A., Catani, F., Della Croce, U., & Leardini, A. (1995). Position and orientation in-space of bones during movement: Anatomical frame definition and determination. *Clinical Biomechanics*, *10*, 171–178.

Chang, C. C., Hsiang, S., Dempsey, P. G., & McGorry, R.W. (2003). A computerized video coding system for biomechanical analysis of lifting tasks. *International Journal of Industrial Ergonomics*, *32*, 239–250.

Chang, C. C., McGorry, R., Lin, J., Xu, X., & Hsiang, S, (2010). Prediction accuracy in estimating joint angle trajectories using a video posture coding method for sagittal lifting task. *Ergonomics*, *53*, 1039–1047.

Coggon, D., Croft, P., Kellingray, S., Barrett, D., McLaren, M., & Cooper, C. (2000). Occupational physical activities and osteoarthritis of the knee. *Arthritis and Rheumatism*, *43*, 1443–1449.

Corlett, E. N., Madeley, S. J., & Manenica, I. (1979). Posture targeting: Technique for recording working postures. *Ergonomics*, *22*, 357–366.

da Costa, B. R., & Vieira, E. R. (2010). Risk factors for work-related musculoskeletal disorders: a systematic review of recent longitudinal studies. *American Journal of Industrial Medicine*, *53*, 285–323.

deLooze, M. P., Toussaint, H. M., Ensink, J., Mangnus, C., & van der Beek, A. J. (1994). The validity of visual observation to assess posture in a laboratory-simulated, manual material handling task. *Ergonomics*, *37*, 1335–1343.

Genaidy, A. M., Simmons, R. J., Guo, L., & Hidalgo, J. A. (1993). Can visual-perception be used to estimate body part angles? *Ergonomics*, *36*, 323–329.

Granata, K. P., & Marras, W. S. (1999). Relation between spinal load factors and the high-risk probability of occupational low-back disorder. *Ergonomics*, *42*, 1187–1199.

Hoogendoorn, W. E., van Poppel, M. N. M., Bongers, P. M., Koes, B. W., & Bouter, L. M. (1999). Physical load during work and leisure time as risk factors for back pain. *Scandinavian Journal of Work, Environment, and Health*, *25*, 387–403.

Hsiang, S. M., Brogmus, G. E., Martin, S. E., & Bezverkhny, I. B. (1998). Video based lifting technique coding system. *Ergonomics*, *41*, 239–256.

Jonsson, G., Persson, J., & Kilbom, A. (1988). Disorders of the cervicobrachial region among female workers in the electronics industry: A two-year follow-up. *International Journal of Industrial Ergonomics*, *3*, 1–12.

Juul-Kristensen, B., Fallentin, N., & Ekdahl, C. (1997). Criteria for classification of posture in repetitive work by observation methods: A review. *International Journal of Industrial Ergonomics*, *19*, 397–411.

Karhu, O., Kansi, P., & Kuorinka, I. (1977). Correcting working postures in industry: Practical method for analysis. *Applied Ergonomics*, *8*, 199–201.

Keyserling, W. M. (1986). Postural analysis of the trunk and shoulders in simulated real-time. *Ergonomics*, *29*, 569–583.

Kilbom, A. (1994). Assessment of physical exposure in relation to work-related musculoskeletal disorders: What information can be obtained from systematic observations. *Scandinavian Journal of Work, Environment, and Health*, *20*, 30–45.

Kingma, I., deLooze, M. P., Toussaint, H. M., Klijnsma, H. G., & Bruijnen, T. B. M. (1996). Validation of a full body 3-D dynamic linked segment model. *Human Movement Science*, *15*, 833–860.

Kociolek, A. M., & Keir, P. J. (2010). Reliability of distal upper extremity posture matching using slow-motion and frame-by-frame video methods. *Human Factors*, *52*, 441–455.

Krosshaug, T., Nakamae, A., Boden, B., Engebretsen, L., Smith, G., Slauterbeck, . . . & Barr, R. (2007). Estimating 3D joint kinematics from video sequences of running and cutting maneuvers-assessing the accuracy of simple visual inspection. *Gait & Posture*, *26*, 378–385.

Leskinen, T., Hall, C., Rauas, S., Ulin, S., Tonnes, M., Viikari-Juntura, E., &Takala, E. P. (1997). Validation of portable ergonomic observation (PEO) method using optoelectronic and video recordings. *Applied Ergonomics*, *28*, 75–83.

Lowe, B. D. (2004a). Accuracy and validity of observational estimates of shoulder and elbow posture. *Applied Ergonomics*, *35*, 159–171.

Lowe, B. D. (2004b). Accuracy and validity of observational estimates of wrist and forearm posture. *Ergonomics*, *47*, 527–554.

Marras, W. S. (2000). Occupational low back disorder causation and control. *Ergonomics*, *43*, 880–902.

McAtamney, L., & Corlett, E. N. (1993). RULA: A survey method for the investigation of work-related upper limb disorders. *Applied Ergonomics*, *24*, 91–99.

Nahmias, S. (2001). *Production and operations analysis* (4th ed.). Boston, MA: McGraw-Hill.

Neumann, W. P., Wells, R. P., Norman, R. W., Frank, J., Shannon, H., Kerr, M. S., & Grp, O. W. (2001). A posture and load sampling approach to determining low-back pain risk in occupational settings. *International Journal of Industrial Ergonomics*, *27*, 65–77.

Neumann, W. P., Wells, R. P., Norman, R. W., Kerr, M. S., Shannon, J. F., & Grp, O. W. (2001). Trunk posture: Reliability, accuracy, and risk estimates for low back pain from a video based assessment method. *International Journal of Industrial Ergonomics*, *28*, 355–365.

Portney, L. G., & Watkins, M. P. (1993). *Foundations of clinical research: Applications to practice*. Stamford, CT: Appleton & Lange.

Punnett, L., Fine, L. J., Keyserling, W. M., Herrin, G. D., & Chaffin, D. B. (1991). Back disorders and nonneutral trunk postures of automobile assembly workers. *Scandinavian Journal of Work, Environment, and Health*, *17*, 337–346.

Roebuck, J. A., Kroemer, K. H. E., & Thomson, W. G., (1975). *Engineering anthropometry methods*. New York, NY: Wiley-Interscience.

Shrout, P. E., & Fleiss, J. L. (1979). Intraclass correlations: Uses in assessing rater reliability. *Psychological Bulletin*, *86*, 420–428.

Spielholz, P., Silverstein, B., Morgan, M., Checkoway, H., & Kaufman, J. (2001). Comparison of self-report, video observation and direct measurement methods for upper extremity musculoskeletal disorder physical risk factors. *Ergonomics*, *44*, 588–613.

Sutherland, C. A., Albert, W. J., Wrigley, A. T., & Callaghan, J. P. (2008). A validation of a posture matching approach for the determination of 3D cumulative back loads. *Applied Ergonomics*, *39*, 199–208.

Tanii, K., & Masuda, T. (1985). A kinesiologic study of erectores spinae activity during trunk flexion and extension. *Ergonomics*, *28*, 883–893.

van der Beek, A. J., van Gaalen, L. C., & Frings-Dresen, M. H. W. (1992). Working postures and activities of lorry drivers: A reliability study of on-site observation and recording on a pocket computer. *Applied Ergonomics*, *23*, 331–336.

van Wyk, P. M., Weir, P. L., Andrews, D. M., Fiedler, K. M., & Callaghan, J. P. (2009). Determining the optimal size for posture categories used in video-based posture-assessment methods. *Ergonomics*, *52*, 921–930.

Xu, X., Chang, C. C., Faber, G. S., Kingma, I., & Dennerlein, J. T. (2010a). Comparing polynomial and cubic spline interpolation of segment angles for estimating L5/S1 net moment during symmetric lifting tasks. *Journal of Biomechanics*, *43*, 583–586.

Xu, X., Chang, C. C., Faber, G. S., Kingma, I., & Dennerlein, J. T. (2010b). Interpolation of segment Euler angles can provide a robust estimation of segment angular trajectories during asymmetric lifting tasks. *Journal of Biomechanics*, *43*, 2043–2048.

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Date received: November 30, 2010
Date accepted: April 22, 2011